Peter D. Stephenson, Katharine Wray, and L. Miguel Encarnação, IMEDIA, Inc.

Using Illustrative Rendering in Visualization to Intuitively Depict Information Quality and Uncertainty

ABSTRACT

We show that illustrative rendering styles such as sketching and stippling can be used in visualization to indicate regions of low information quality, including uncertainty and low importance. A series of user studies are overviewed in which the effectiveness of using illustrative techniques for communicating information quality in 2D and 3D geospatial visualization is evaluated. The participants of the user studies were from the general population and therefore had no specialist training in visualization or the topic being visualized. To make the case for using this approach in real world applications, we present a set of case studies in which we developed examples from sonification and mine detection systems.

INTRODUCTION

Understanding the quality of information, including certainty and importance, is vital to the investigative and decision making processes of the analyst. In this project we look outside of the field of computer graphics and visualization to evaluate how other designers communicate quality in their work. We now seek to include these ideas in the visualization process with the aim of making the communication of quality through the visual representation as intuitive as possible.

In traditional pen-and-paper design, when the designer starts to develop an idea they typically commence with a rough sketch, which provides very little detail but offers an overall shape or structure. As the design progresses, more detail and definition are added and it is inherently understood that the design is becoming more concrete. While roughly drawn images connote uncertainty, realistic images do not. Roughly sketched regions of a drawing provide context but their significance is diluted compared to more highly rendered regions of the image.
A problem faced when trying to communicate a quality or certainty through computer-generated visualization is that traditional rendering techniques in computer graphics were designed to be as photorealistic as possible. Therefore by using these techniques to render low quality information, we are confronting the inherent trust that people place in realistic looking images.

The development of non-photorealistic rendering (NPR) techniques in computer graphics (Lansdown and Schofield 1995) provides us with a toolset to use illustrative rendering styles that can be used to communicate quality and uncertainty. In this paper we describe an initial investigation into the use of these techniques to mimic the traditional design process for describing the quality of information in visualization. We also present a series of case studies for application of the approach and discuss the benefit we see in reducing the amount of training required by analysts, decision makers and general public in understanding visualizations that use these techniques due to their intuitive nature.

BACKGROUND

The communication of uncertainty in visual representations is not a new problem. The use of error bars in two-dimensional charts (Olston and MacKinlay 2002) is an example that any former science student will be familiar with. Extending this idea of applying an expressive shape to a computer-generated visualization is the use of glyph elements (Pang, Wittenbrink and Lodha 1997, Wittenbrink et. al 1996), which allow for an in-depth exploration of the quality of the information but add to the visual complexity and can prove difficult to place spatially in a three-dimensional rendering (Pang, Wittenbrink and Lodha 1997).

Another approach to visualizing the quality of information is to map it to one of the standard visual quantities used in visualization (Pang, Wittenbrink and Lodha 1997). Of these, color (Schmidt 2004), opacity (Djurcilov et. al 2001, Grigoryan and Rheingans 2003, Rhodes et. al 2003) and texture (Huang 2005, Rhodes et. al 2003) have been most frequently used. If an evaluation of information quality is the focus of the analyst's attention, overloading visual parameters is a valid approach. However this approach relegates the communication of information quality to a separate analysis and therefore a more intuitive technique that does not confuse the visual representation should be preferred in various situations.

We contend that using illustrative rendering styles implemented as NPR techniques to delineate regions of low quality is an intuitive and implicit form of communication that, if applied correctly, should not interfere with the focus of an analyst. Instead it dilutes the visual impact of lower quality information in favor of higher quality information while preserving its context. This notion is supported by Schumann et. al (1996) who explored the perception of users of the system and concluded that in comparison with shaded or CAD plot images, users perceive the illustratively rendered images to be less complete. An example of how effective illustrative rendering techniques can suggest information while not confusing it with knowledge is the archeological visualization system presented by Strothotte, Masuch and Isenberg (1999). They visualized lost ancient architecture by using line drawings in which lines of various weights were used based on the certainty of what was being visualized once existed.

OVERVIEW OF USER STUDIES

To investigate how illustrative rendering styles can be used to communicate information quality in visualization, we conducted a series of user studies that demonstrated that techniques such as stippling, sketching and painting, and outlining are effective in communicating low information quality in a visual representation.

In each of the user studies we presented the participants with images that had been illustratively rendered by an information designer using Adobe Photoshop®. Čadik (2004) reviewed the artistic rendering filters available in Photoshop and showed that they compare favorably to images produced using NPR techniques. Utilizing this process we were able to prototype and analyze the visualization techniques more efficiently before implementation. It also provides the designer greater access to and flexibility with the described research, which is important as it is their experience and knowledge we seek to utilize.

The participants chosen to take part in the user studies were chosen to have no technical background, prior priming nor specific training in either visualization or the field from which the dataset being visualized was derived. This is because we wanted to evaluate how intuitive the use of illustrative rendering techniques was in communicating information quality, and its potential for training. Due to the low level of familiarization with visualization we required from our participants, we had to choose datasets for the user studies that were understandable by the general population. Therefore we chose satellite imagery for a two-dimensional study and a medical dataset for our three dimensional study.

User Study: Connotation of Quality

The first user study was to determine if people consider areas within a digital image that are rendered using illustrative techniques as depicting low or high quality information when compared to regions left untouched. We also wanted to compare applying the illustrative technique in gray scale against keeping the chromaticity of the original image in the illustrative region.

We therefore presented eight images to 37 participants with each image containing one illustratively rendered and one untouched region, and asked the participant to define which region conveyed a greater sense of quality of information. The eight images consisted of two images altered using each of the four illustrative styles, with one in grayscale and the other maintaining the chromaticity of the image. The dataset used was a satellite image of a small desert town. Examples of the images are presented in Figure 1.

Overall, 95.6% of participants chose the untouched section of the image to be that of the highest quality, with a standard deviation of only 10.3%. Of the individual illustrative rendering techniques described in Table 1, the poorest performing technique was outlining when used with full color with a rate of 81%, which, while still confirming the hypothesis, is noticeably lower than the other techniques. All of these results were shown to be statistically significant using the binomial distribution probability test. The probability that the results were obtained by chance are p = 1.3 x 10-67.

	Stipple	**Sketch**	**Paint**	**Outline**
Grayscale	97%	97%	97%	100%
Color	95%	97%	100%	81%

Table 1: The percentage of responses indicating that the illustrated region of the image conveyed low quality information.

We cannot differentiate the performance of the illustrative rendering style in grayscale or with the chromacity of the original image with statistical significance. We also cannot order the techniques except for the color version of the outlining technique, which underperforms the others. We believe that the illustrated region in this case increases the contrast of edges in the images and therefore emphasizes detail that may invoke the perception of greater certainty. However this question requires further investigation.

(a) Outlining technique in grayscale. **(b) Sketching style in color.**

Figure 1: Sample images from the first user study.

User Study: Level of Quality

The second study was designed to determine whether a graduation in intensity of an illustrative rendering technique can imply a different level of quality within a visualization. The task is based on a legend relating the increasing graduation of four levels of an illustrative technique to four levels of quality being very good, good, poor, and very poor. The task was divided into three parts, distinguished by when and how often the participant was shown the legend.
The dataset used was a maximum intensity projection (MIP) of a computed tomography (CT) scan of the male human foot dataset from the Visible Human Project of the National Museum of Health. The images resemble X-ray images and therefore participants could understand the dataset and the visualization without training. Participants with medical training however were excluded from the study. The data in the following analysis was gathered from twelve study participants.

The three parts to this user study were:

- Part A: In the first part of the task, the participants were shown the legend next to each of the images as described in Figure 2. There were 16 images in total, comprising images of the four illustrative rendering techniques in four graduations. Each of the four images from each technique were presented in turn but in random order.
- Part B: In the second part of the task, the participants were shown the legend separately before each sample image was displayed; therefore the legend was not displayed beside the sample image.
- Part C: In this final part of the task, the legend was not shown at all before or during the sequence of sample images.

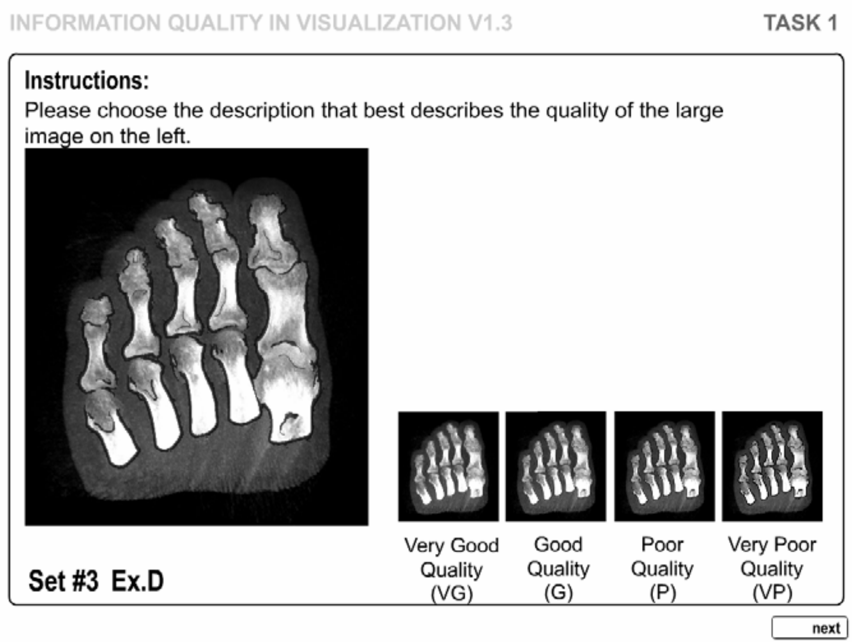


Figure 2: A screenshot from Part A of the user study. The image legend on the right shows the full gradation of illustrative rendering, and the participant is asked to identify the correct description of the large image.

The results are summarized in Table 2. They show with statistical significance that the participants can determine the level of quality when described by a graduation of illustrative rendering. The most effective techniques are sketch and stipple but no significant difference between them was determined using a Student-t test.

	Stipple	Sketch	Paint	Outline
Part A	75%	69%	40%	50%
Part B	90%	81%	73%	54%
Part C	54%	79%	60%	54%
Total	73%	76%	58%	53%

Table 2: The number of correct answers by subtask.

In order to explore the importance of training and the use of a legend in determining information quality levels in artistic rendering, we compared the individual subtasks. We discovered a somewhat surprising result that error values for Part A, where the legend was displayed throughout the survey were consistently higher than for Part B in which the legend was shown prior. We believe that since Part A was the first time the participants were introduced to the images, the results may indicate that some training is required for the participants to determine different levels of information quality. However, given the length of the survey of Part A, this training is not substantial. The error rates for the survey of Part C, where no legend was used, were higher than the previous two parts. Therefore, access to a legend for comparing illustrative rendering and quality levels is important.

User Study: Distinguishing Regions

This user study explored how well participants can distinguish illustratively rendered regions within an otherwise base-rendered image. The dataset used was the MIP rendered foot dataset. In this user study, the participants specified the regions that they believed to be illustratively rendered by choosing the cells of a 6x6 grid placed over the images. The participants chose those cells of the grid they believed contained illustratively rendered regions. For this task, both the correctly and incorrectly identified cells of the grid were recorded as part of our data, as both influenced our analysis of the efficacy of the techniques. Incorrectly identified cells include both false negatives and false positives.

The results for this task are collated in Table 4 and show that the illustrative techniques can be determined from the base rendering style. The outline technique has a significantly higher error rate according to the t-Test than the other techniques, however no other comparison of the other techniques was significant.

	Stipple	Sketch	Paint	Outline
Correct	87%	91%	89%	63%
False positive	13%	9%	11%	37%
False negative	14%	14%	39%	9%

Table 3: Determining illustrative rendering styles from the base rendering style.

User Study: Locating Illustrated Regions in 3D

In the last user study, we wanted to determine how well an illustratively rendered region of a three-dimensional dataset could be tracked under rotation. A common problem in quality visualization, particularly when using glyphs, is that analysts cannot identify the precise location of the area of uncertainty. While the rendering techniques are not installed in an interactive system, we proposed that the participants could identify which of two image represented the same three-dimensional object in which a section had been illustratively rendered. For each of the four rendering styles, three trials were carried out. The results are described in Table 4.

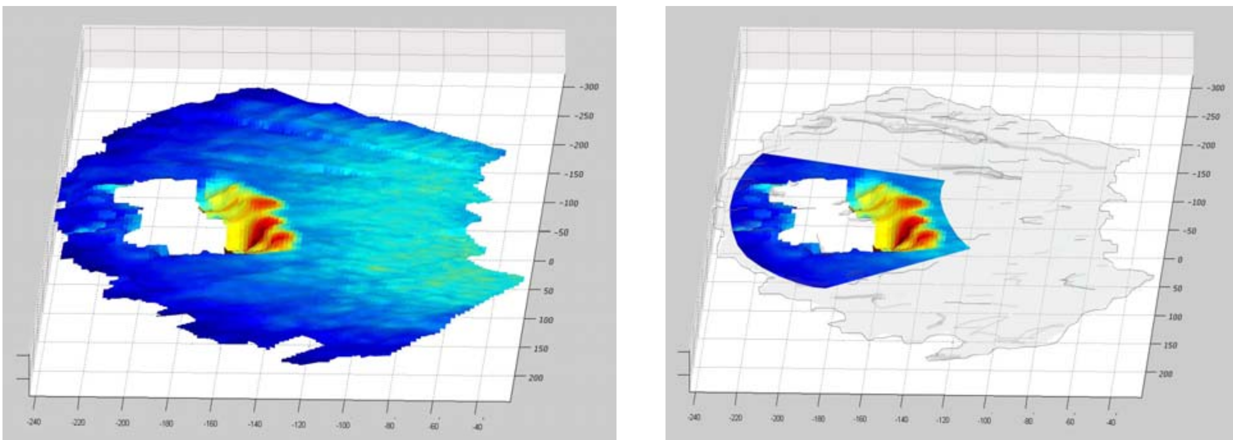
	Stipple	Sketch	Paint	Outline
Trial 1	92%	8%	67%	100%
Trial 2	92%	75%	33%	25%
Trial 3	83%	92%	50%	58%
Totals	**89%**	**58%**	**50%**	**61%**

Table 4: The results of Task 3 by trial and technique.

The results show with statistical significance that the position of illustratively rendered regions in a rotated three-dimensional dataset can be correctly located for each illustrated rendering style except for the paint technique. These results should only be considered preliminary and more experiments with different datasets using interactive visualization tools should be conducted.

CASE STUDIES

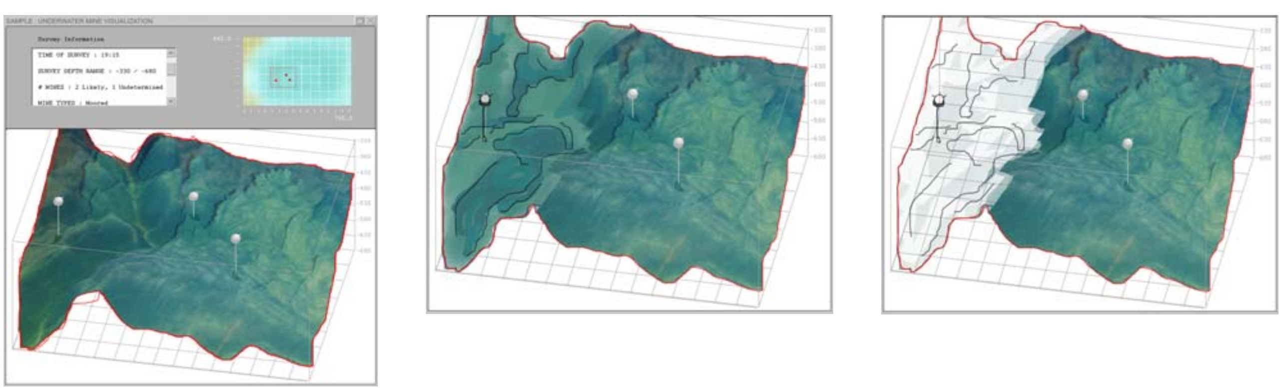
In Figure 3(a) we show a rendering of a sunken submarine that was detected using a series of sonar pings. The surface ship moved over the submarine and collected the data, which was then fused based on the position of the ship when each ping was taken. The most importance parts of this fused dataset are the peaks due to the submarine and the sonar shadow the boat casts on the ocean floor. In this original rendering, the ocean floor possesses a similar visual importance to the submarine and its shadow. In Figure 3(b), we have replaced the high quality rendering of the ocean floor with an illustrative style similar to sketching. While the context of the ocean floor is apparent, the analyst can focus of the most important regions of the visualization.



(a) Original visualization using MatLab. **(b) Using illustrative rendering to reduce background information while maintaining context.**

Figure 3: Example sonar sounding of a sunken submarine.

When visually representing the results of fusing sensor datasets, it is difficult to communicate where information is more uncertain due to the different range, resolution, accuracy and precision of the sensors. In Figure 4 we evaluated the use of illustrative rendering for describing the regions of low probability in a mine hunting scenario. The elevation map is actual section of ocean floor. We wanted the designers to communicate the location of two known mine



(a) Original. **(b) Painted.** **(c) Sketched.**

Figure 4: Results of a mine survey.

placements, and the possibility of a third. In Figure 4(b) and (c) we used two different rendering styles to communicate the lack of certainty regarding the placement of the third. In each case, while the quality of the rendering is not high, the intuitive lack of belief placed in the visualization of the illustrated region was what we were seeking.

CONCLUSION

We have overviewed a set of user studies in which we showed that illustrative rendering techniques can be used to describe information quality in 2D and 3D geospatial datasets. We were able to show with statistical significance that:

- The information presented in regions of an image that are treated with illustrative rendering techniques are determined to be of lower quality or less certain information than those untreated. There was no significant difference measured between colored and grayscale illustrative rendering implementations.
- The illustratively rendered regions of an image can be distinguished from the base rendered regions in the same image and these regions can be determined under various rotations.
- The graduation of the illustrative rendering style applied can be associated with a degree of information quality.

The user studies are based on the assumption that image processing techniques yield similar results to implementing NPR techniques in a rendering system, which has support (Čadik 2004). We have however only included four illustrative styles in the study. The results of this work will therefore guide the implementation of illustrative techniques in a visualization system. A second round of user studies are also necessary to confirm the results, which should include an evaluation of how much training is required in evaluating the information presented. We also wish to evaluate these techniques for use in a broader range of datasets other than 2D and 3D geospatial datasets.

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Dr Peter Stephenson *a Senior Scientist with IMEDIA, Inc., where he conducts research in digital geometry, visualization, volume rendering, edutainment, and online learning systems. He is an Adjunct Professor at the University of Rhode Island. Dr. Stephenson holds a BSc (Hons) in Mathematics and Computer Science with Honors in Computer Science, and a PhD in Computer Science from James Cook University in Australia. He has also studied Science Communication at the Australian National University. Dr. Stephenson is a member of the ACM and IEEE Computer Society.*

Katherine Wray *is an Information Designer with IMEDIA, Inc. She has a Bachelor in Fine Arts in Industrial Design from the Rhode Island School of Design in Providence, Rhode Island.*

Dr. Miguel Encarnação *is the CEO and CTO of IMEDIA, Inc. and an Adjunct Professor at the University of Rhode Island. He holds an BS and M.S. in Computer Science from the Technische Universität Darmstadt, Germany, and a Ph.D. in Computer Science from the Universität Tübingen in Germany. He is a member of the editorial board of IEEE Computer Graphics and Applications, a member of the ACM & IEEE Computer Societies, and a member of the European Graphics Society.*